

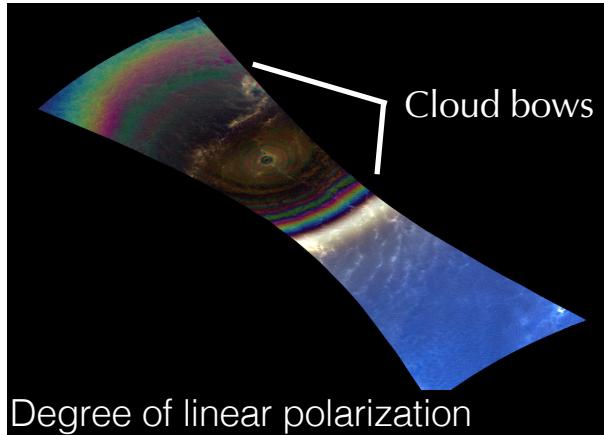
Progress on Inversion Algorithm Development for Polarimetric aerosol retrievals using AirMSPI

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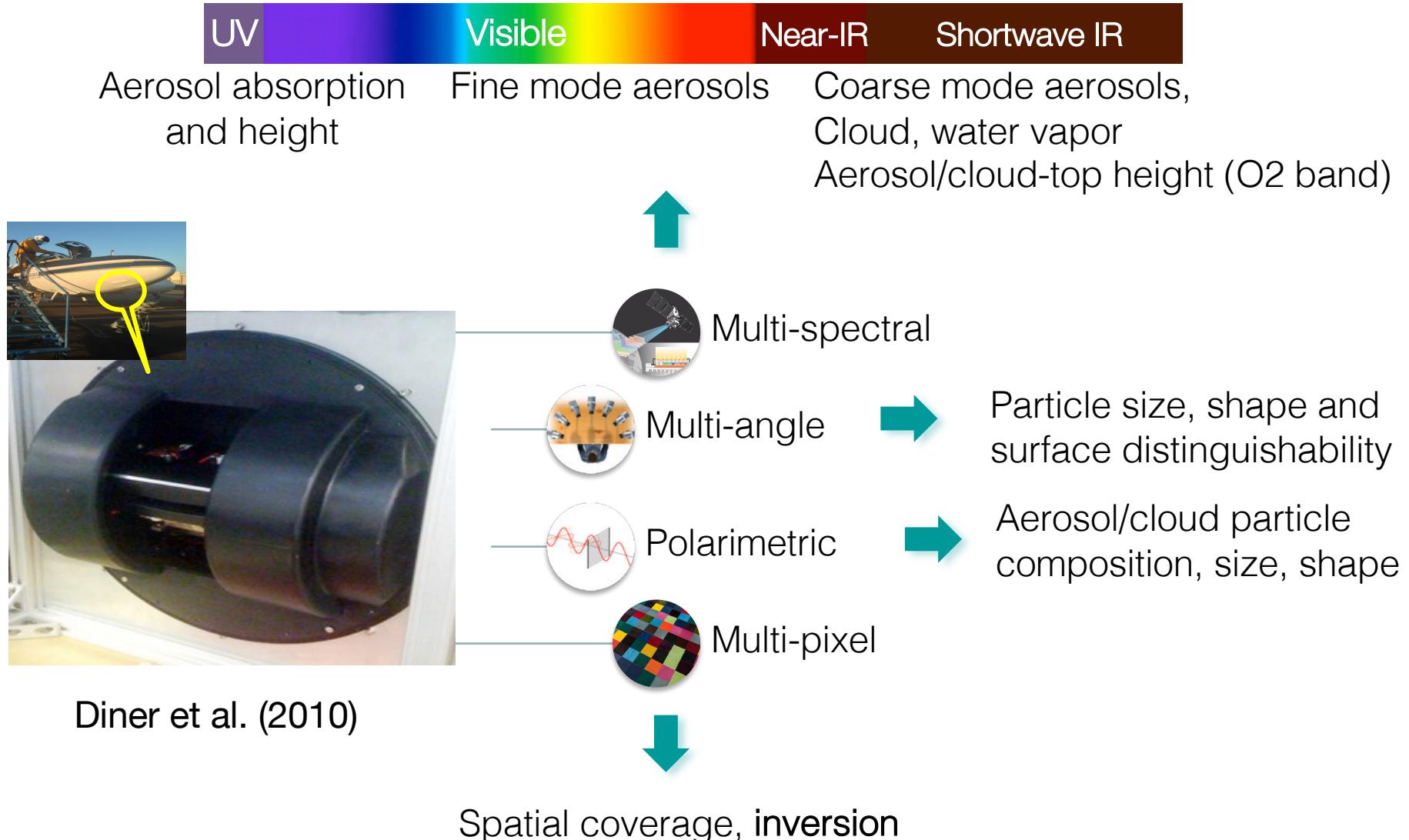
Oleg Dubovik, *University of Lille*

Yoav Schechner, *Technion - Israel Institute of Technology*



Multiangle Spectro-Polarimetric Imager (MSPI)

1

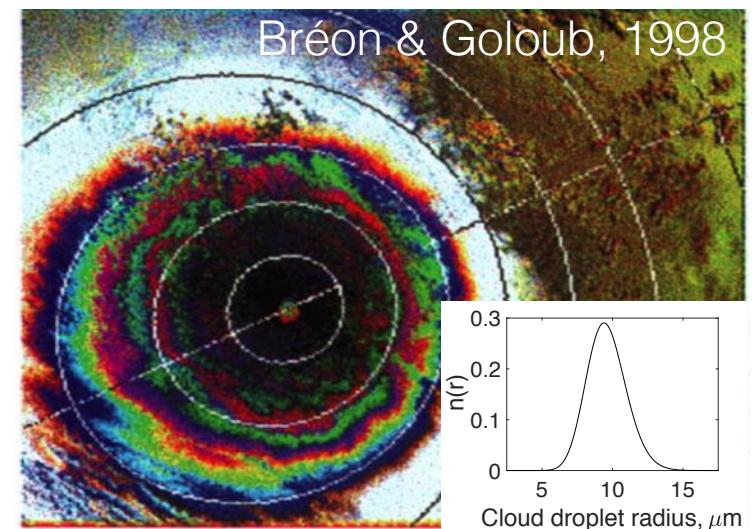
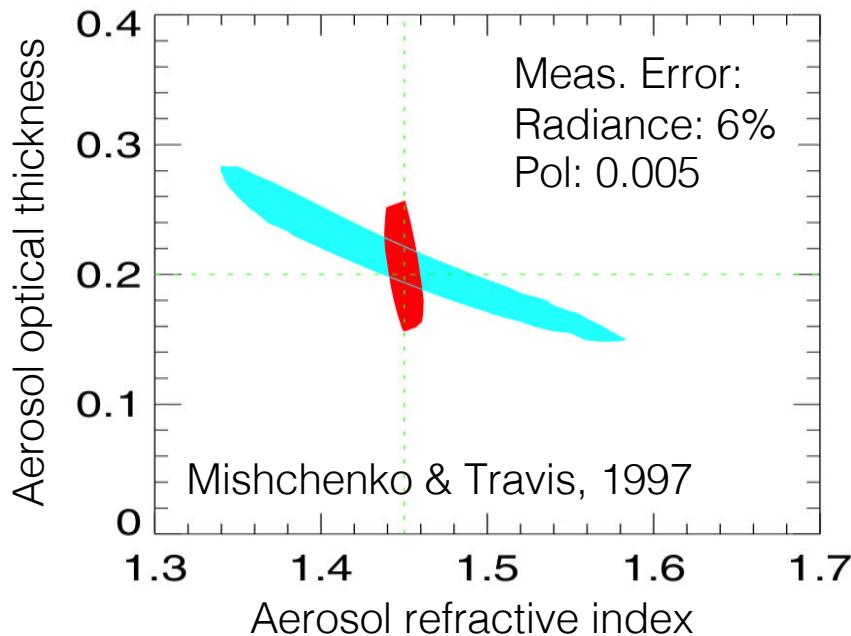


Why polarimetry ?

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The candidate measurement approach considered for the ACCP mission includes a polarimeter, which is demonstrated to constrain

- aerosol size, type, composition, absorption and height
- cloud particle size and shape, distinguishes liquid droplet or ice particles

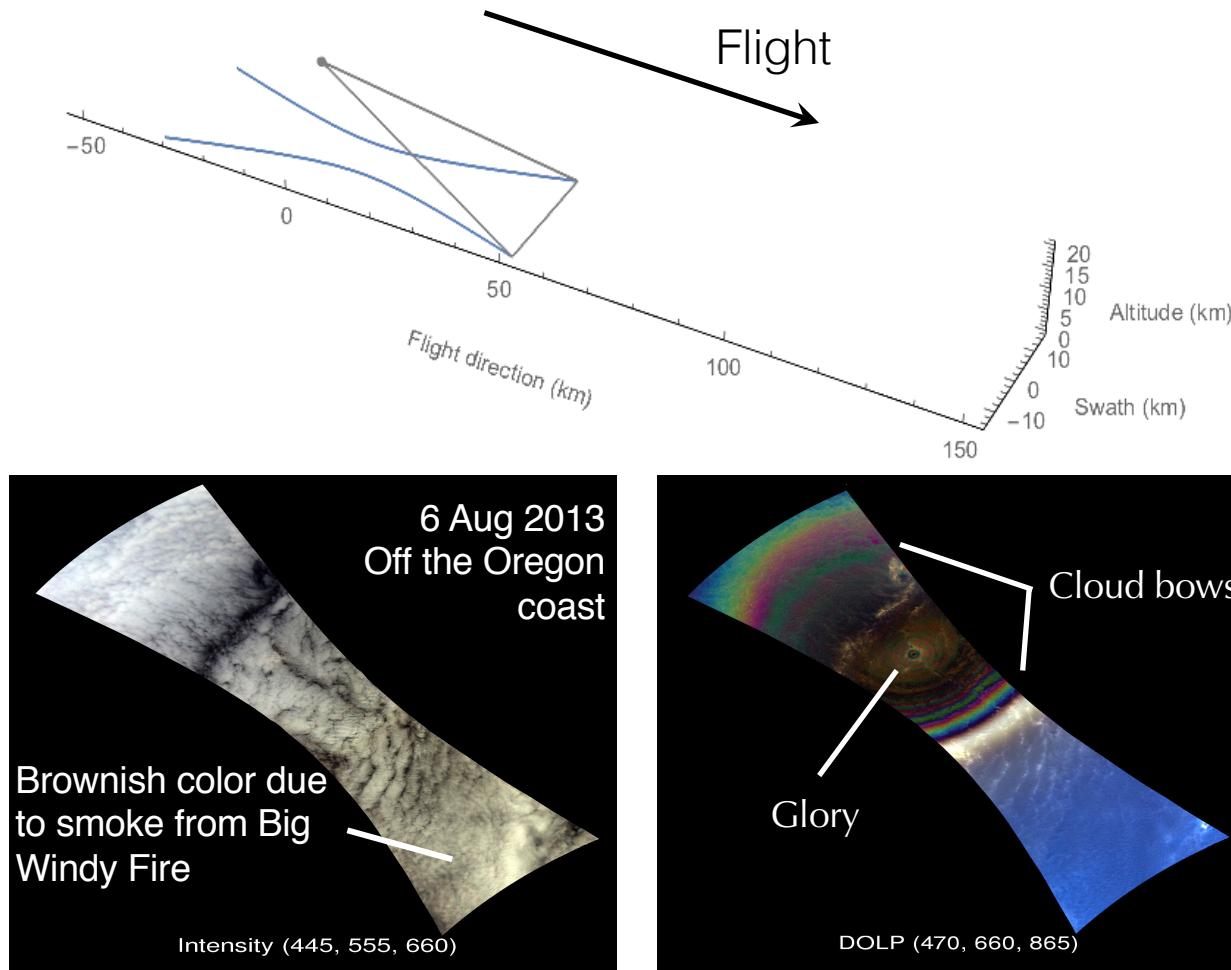


POLDER polarimetric imagery of cloudbow

Sweep view of cloud

3

View area: 20 km x 80 km view area; Resolution: 25 m



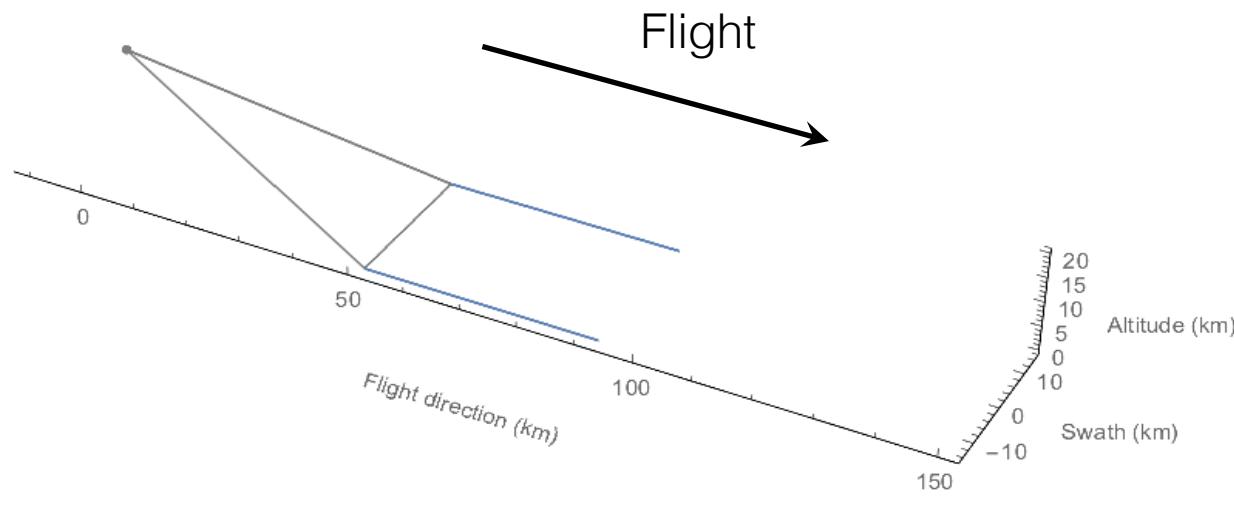
By participating in multiple NASA field campaigns (ORACLES, PODEX, etc), AirMSPI provides observational constraints on

- Climate-quality aerosol remote sensing (*Xu et al. 2017*)
- aerosol-cloud interactions (*Xu et al. 2018*)
- cloud, ocean, and land characterization (*Xu et al. 2016*)

Step-and-stare view of ocean/land

4

View area: 10 km x 11 km view area; Resolution: 10m



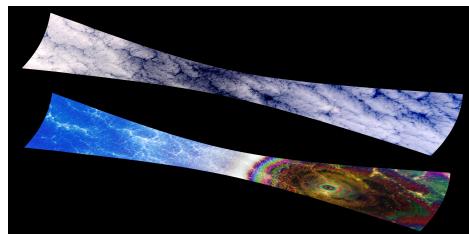
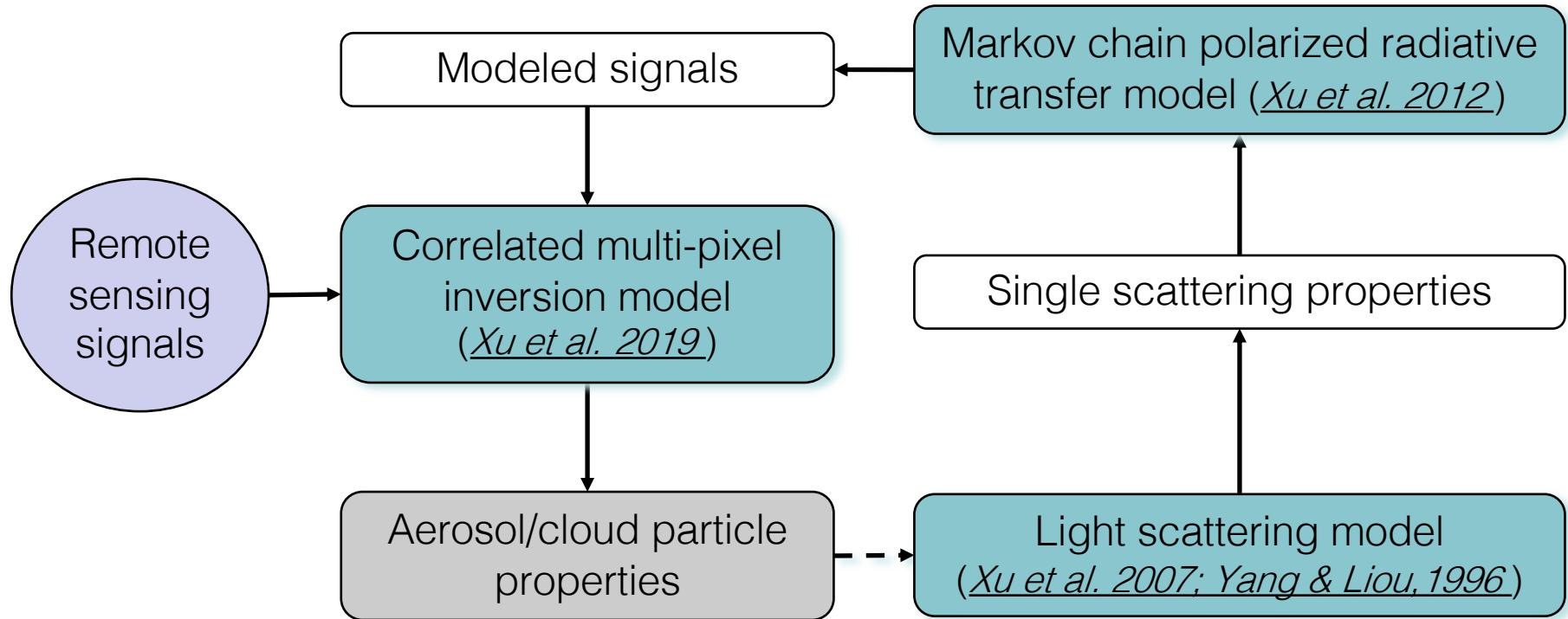
355, 380, 445, 470*, 555, 660*, 865*, 935 nm (*polarized)

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Polarimetric remote sensing algorithm

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Aerosol + cloud retrieval



Aerosol + ocean retrieval



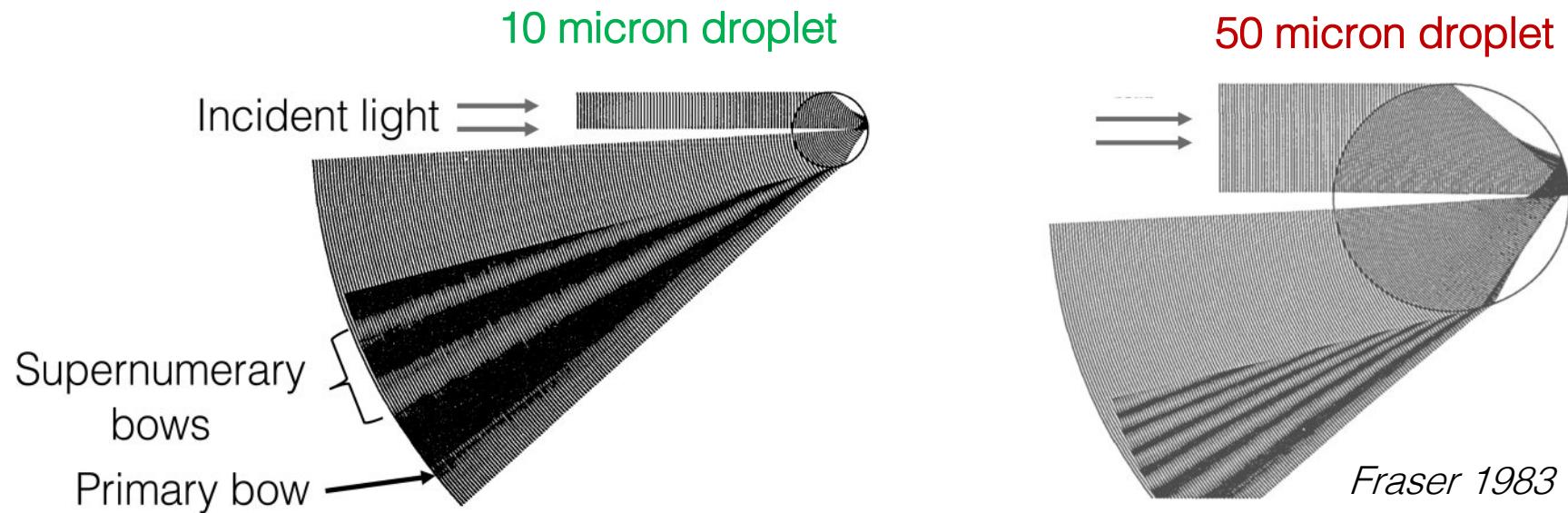
Aerosol + land retrieval

Coupled retrieval of stratocumulus cloud and above-cloud aerosol properties to help

- investigate aerosol and cloud interactions
- characterize cloud albedo, liquid water content, drizzle formation.

Cloudbow sensitivity to cloud property

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Number of fringes → cloud droplet size

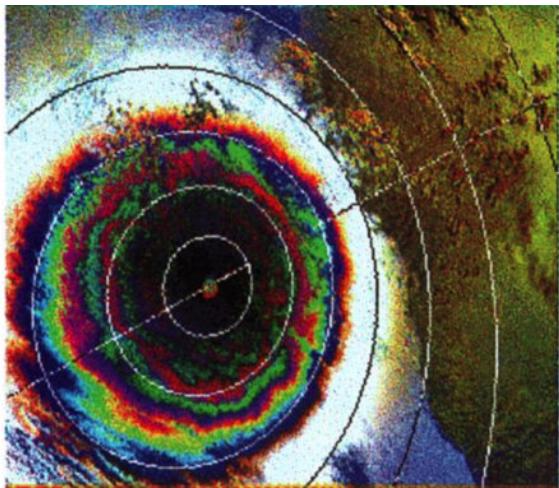
Contrast of fringes → droplet dispersion

Polarimetric cloudbow imaging

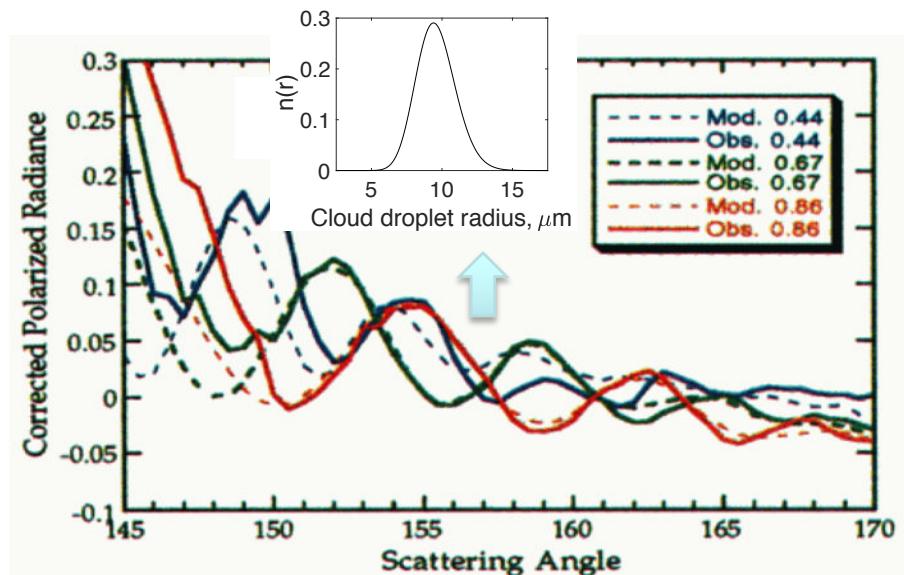
8

Where are we ?

POLDER polarimetric cloudbow imaging allows **one** droplet size distribution estimate from **one** image (e.g. $1600 \times 2200\text{km}^2$, Bréon and Goloub 1998).



POLDER imagery over Atlantic ocean and Southern Africa (Bréon and Goloub, 1998)

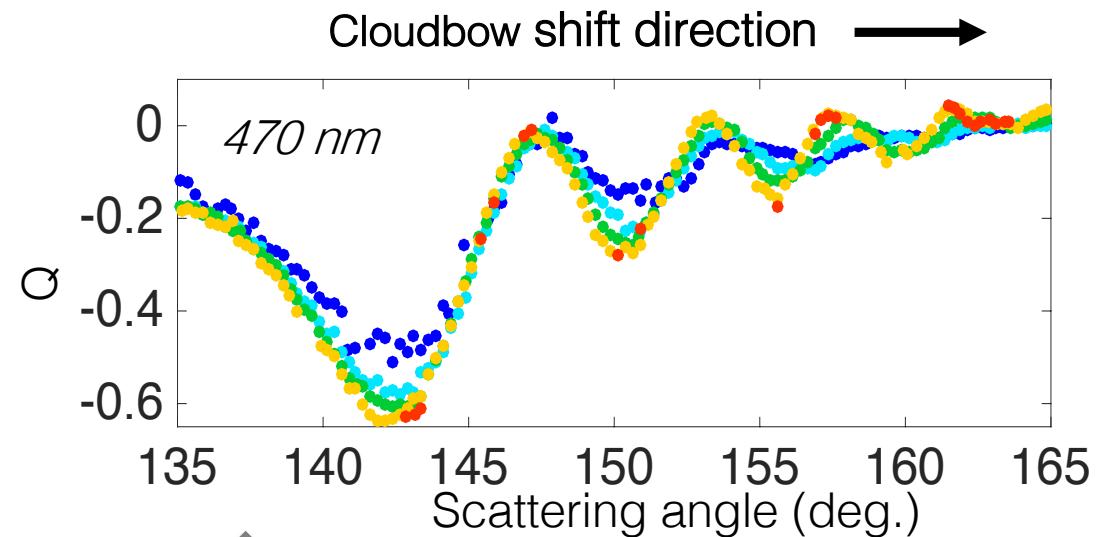
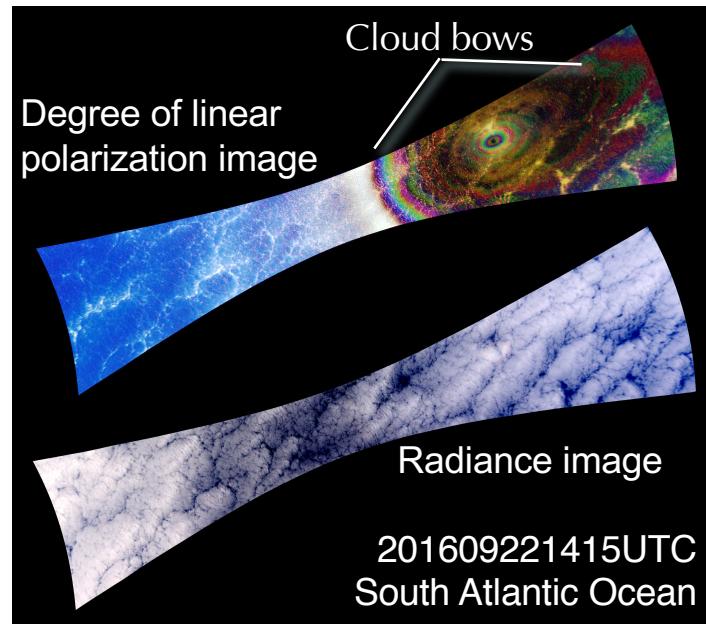


Where are we going ?

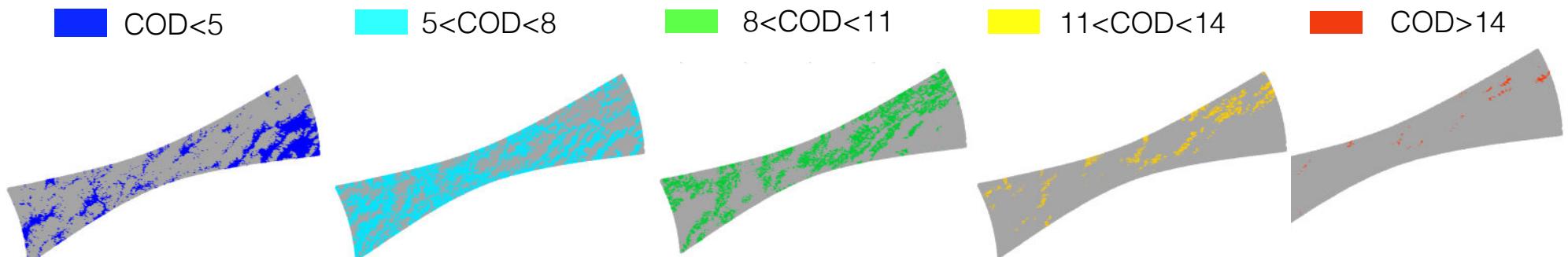
1. Can we resolve pixel-scale droplet size distribution of a single cloud ?
2. Can we simultaneously retrieve above-cloud aerosol (ACA) and cloud properties ?

Cloud optical depth (COD) dependent bow shifts

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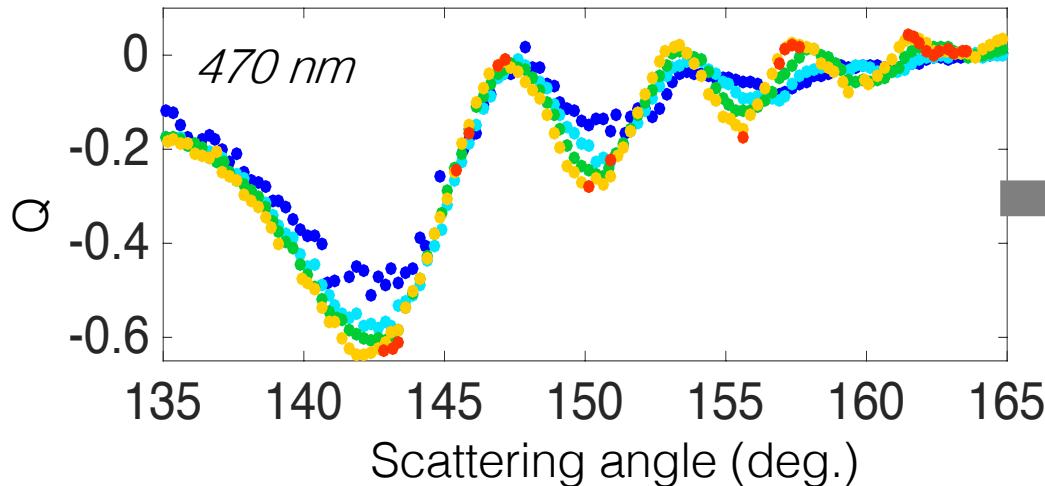
↑ Plot polarized radiance in 5 COD bins



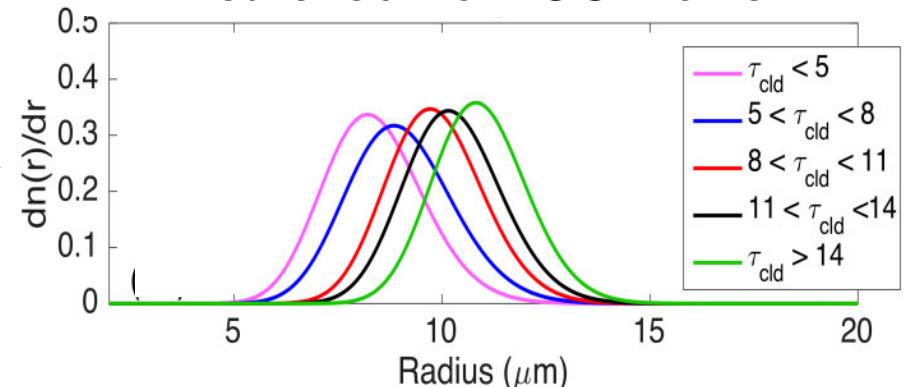
AirMSPI observes COD-droplet size relation

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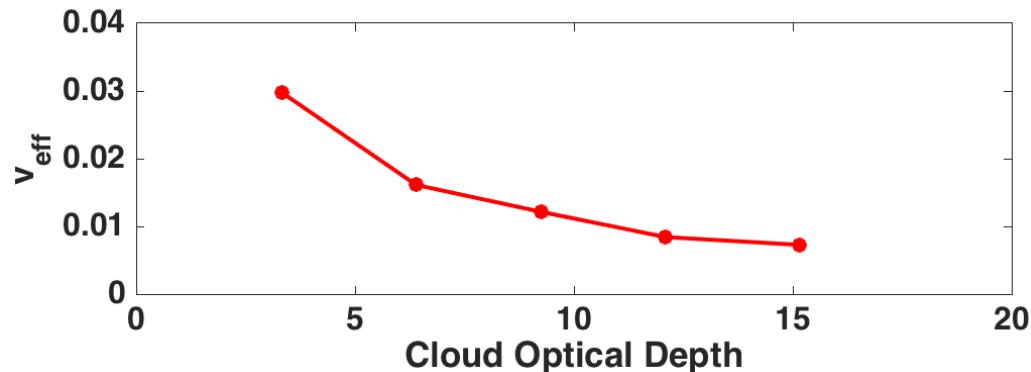
Cloudbow shift



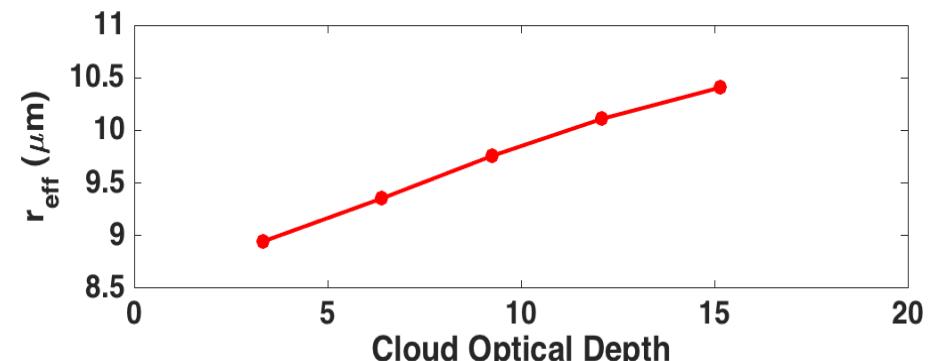
Droplet size distribution (DSD)
retrieved from COD bins



Droplet dispersion (variance) ν_{eff} vs COD

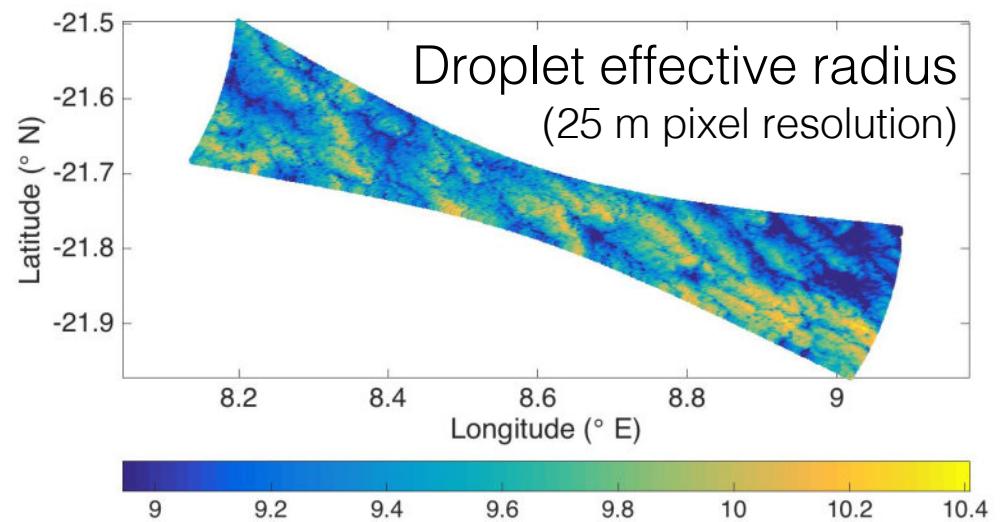
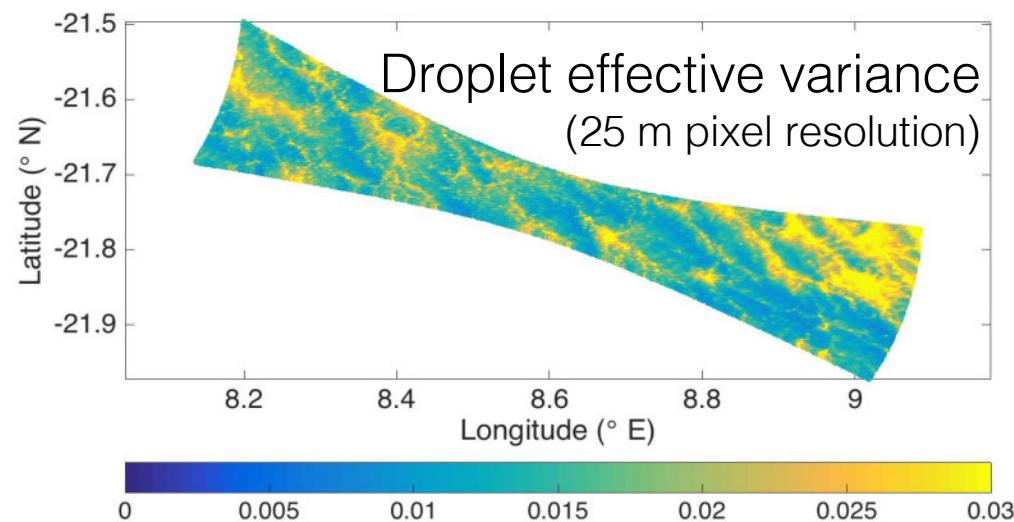
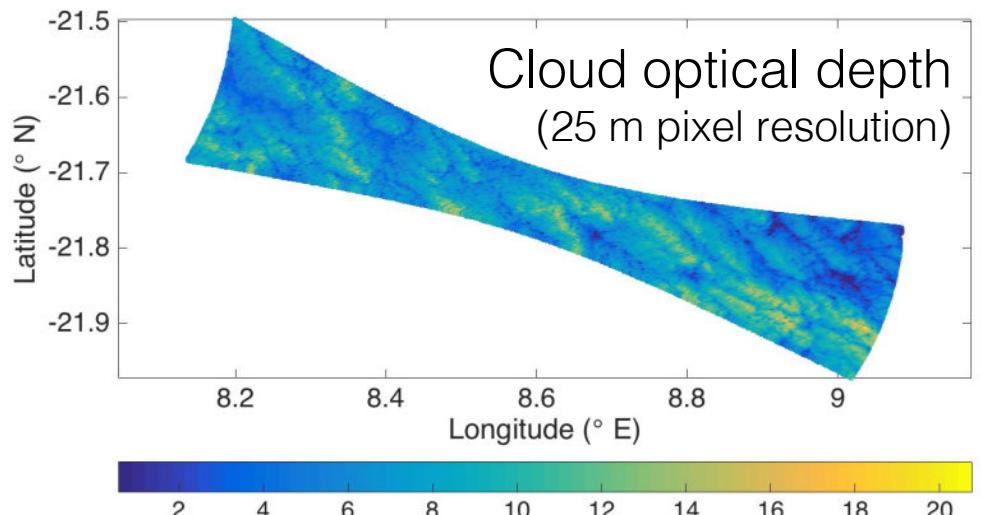
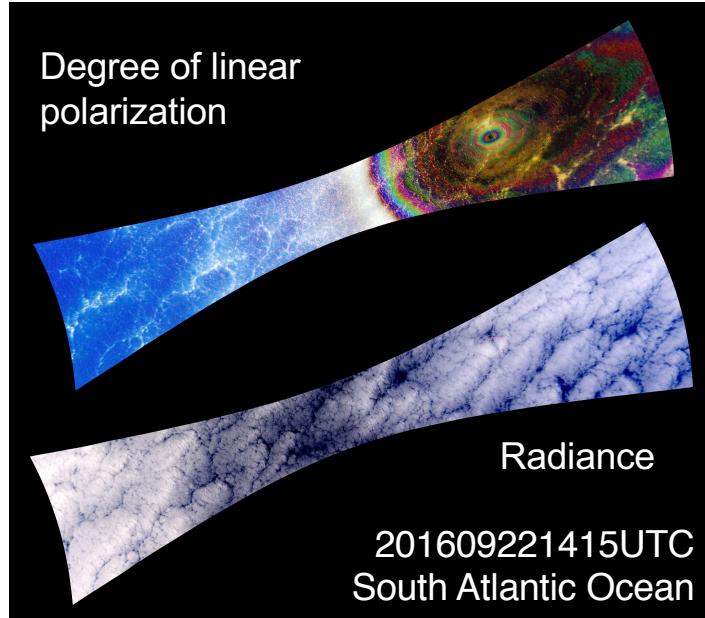


Effective radius r_{eff} vs COD



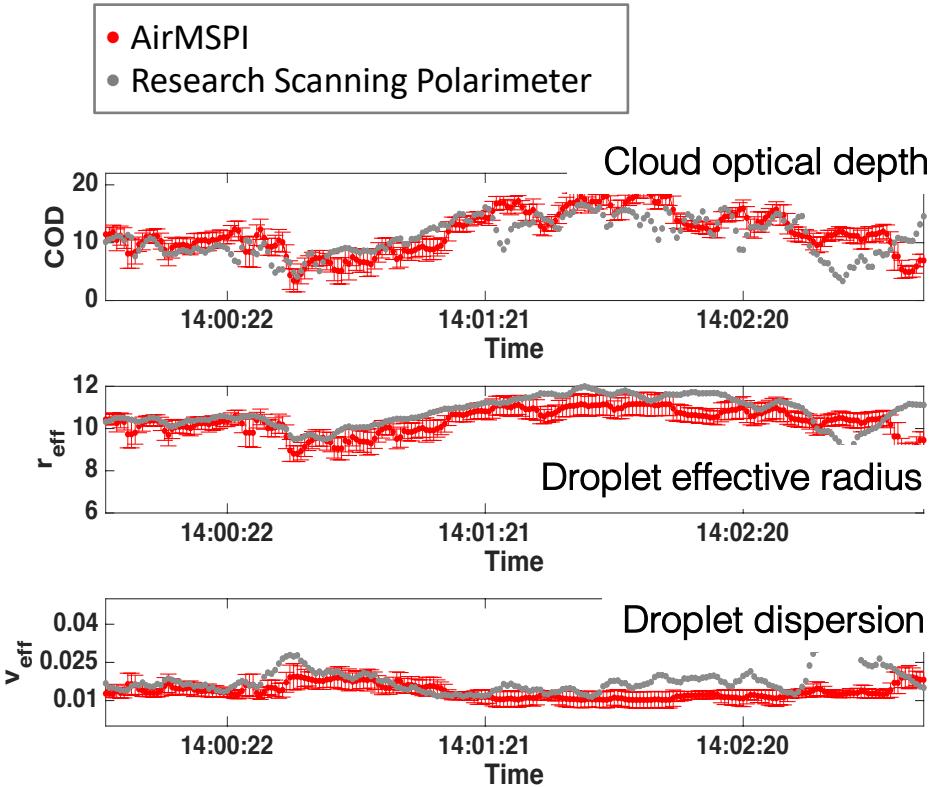
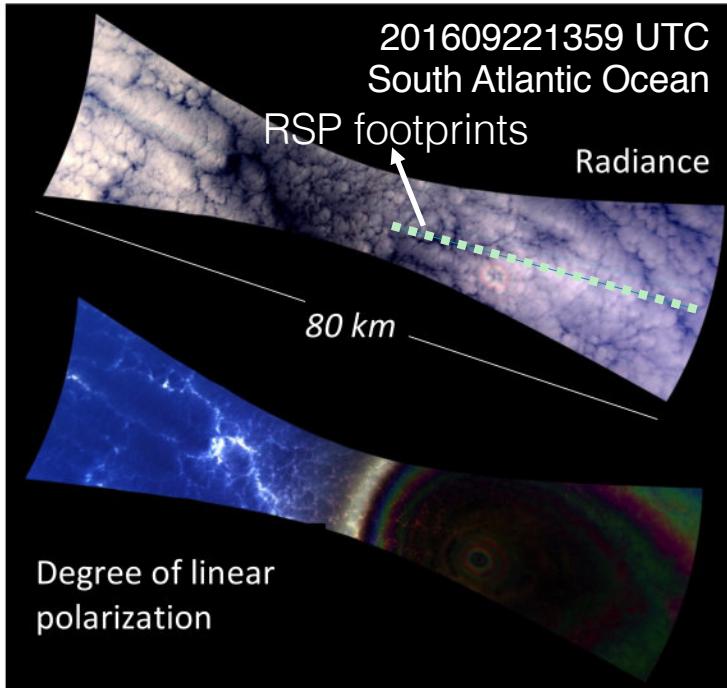
Pixel-scale droplet size distribution retrieval

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Validation of pixel-scale droplet size retrieval

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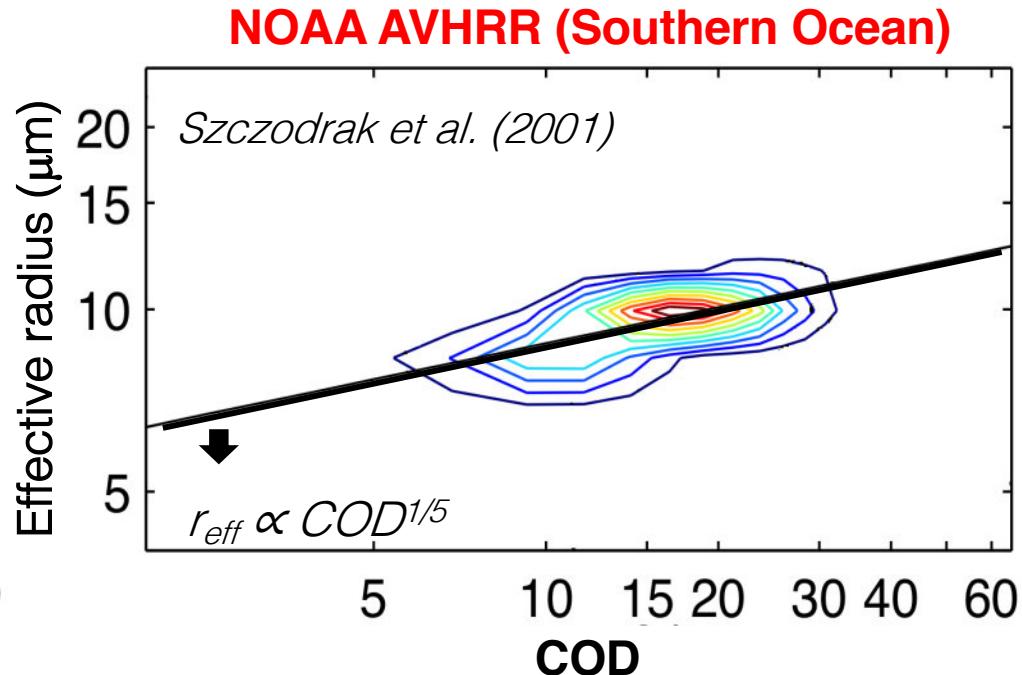
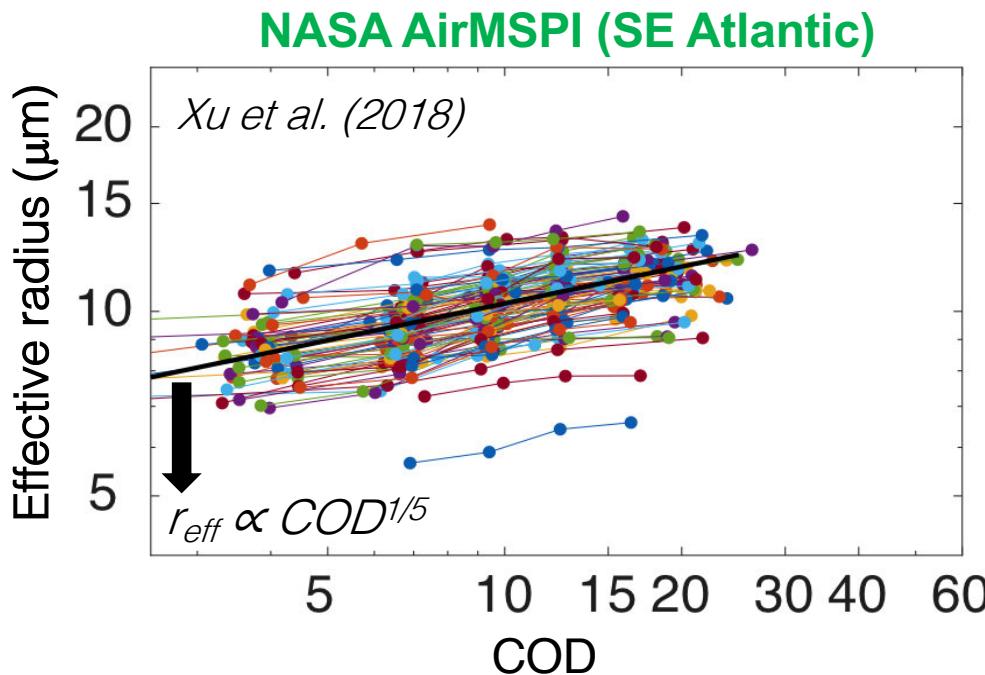


Xu et al., 2018

AirMSPI pixel-scale cloud optical depth and droplet size retrievals show consistency with Research Scanning Polarimeter (RSP)'s results for marine stratocumulus clouds off the coast of Namibia.

Validation of COD-droplet size correlation

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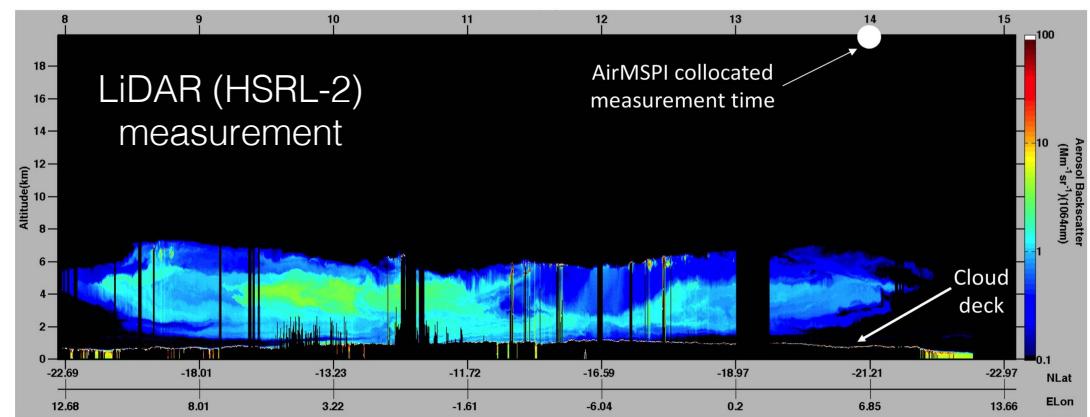
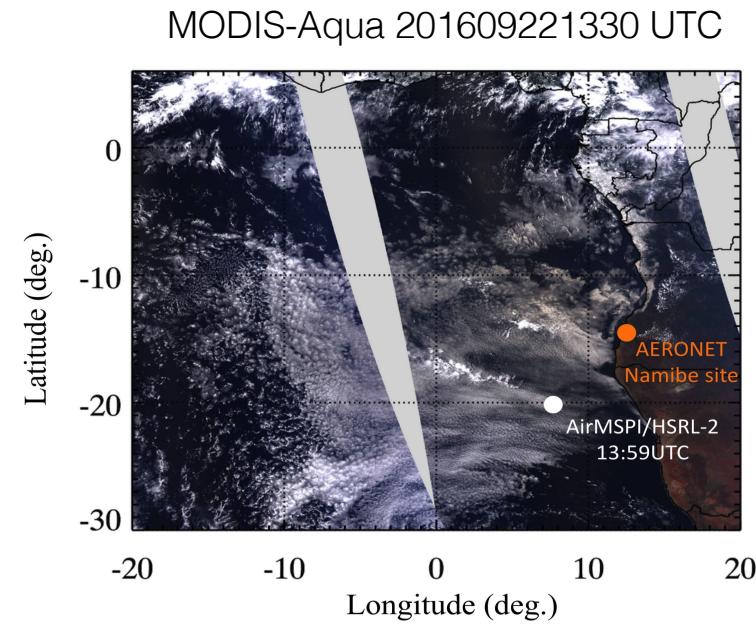
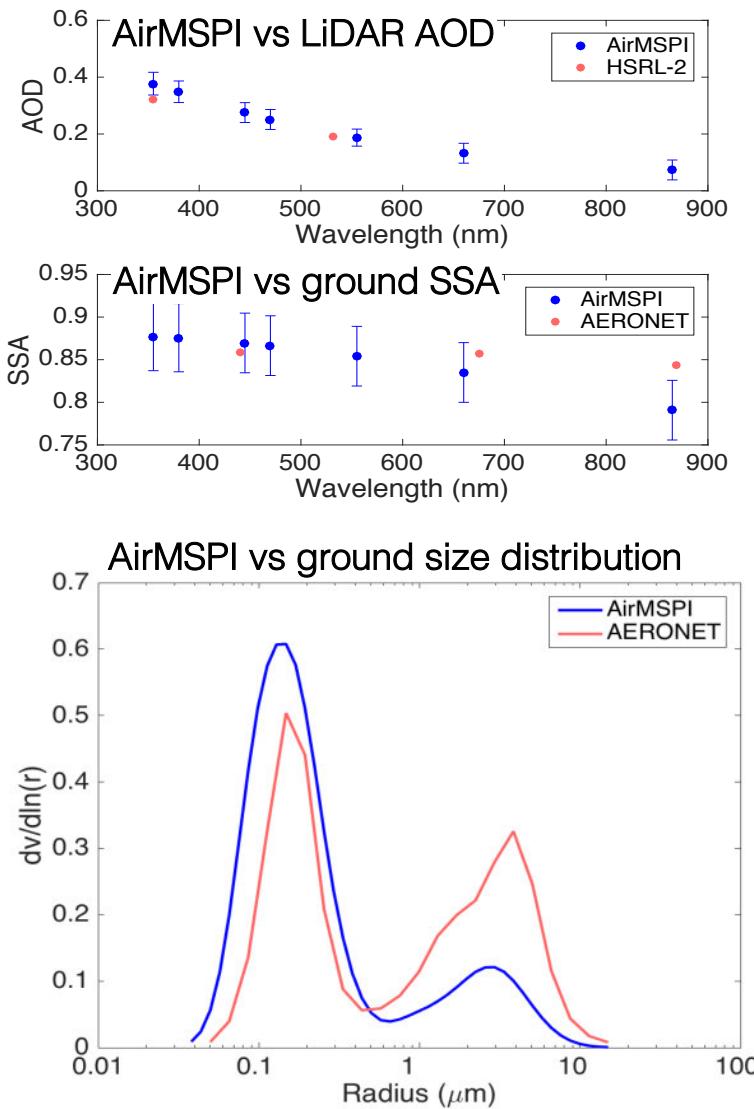


Positive r_{eff} -COD correlations retrieved for stratocumulus cloud from

- AirMSPI polarimetric imaging (25m resolution, 20x80 km² extent)
- AVHRR radiometric imaging (1 km resolution, 256 x 256 km² extent)

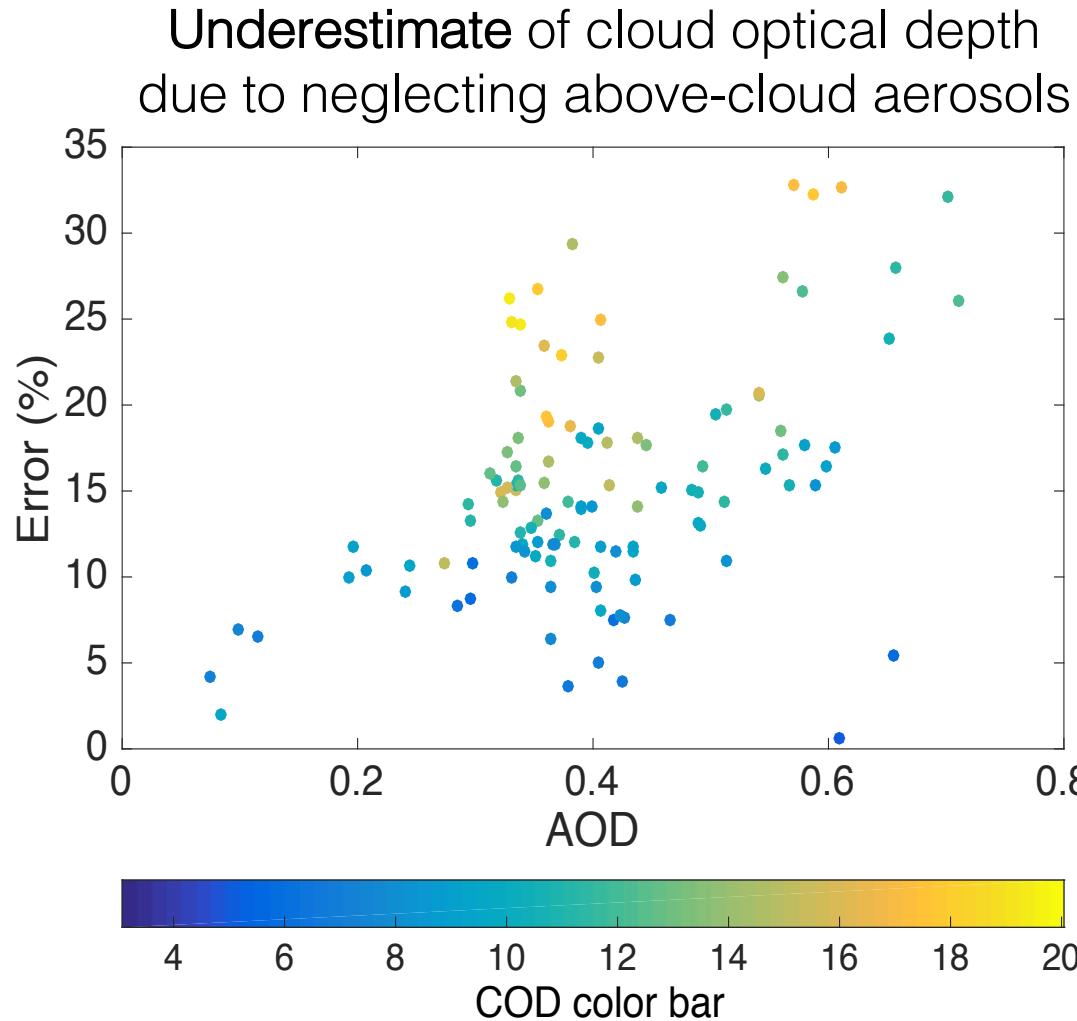
Above-cloud aerosol validation

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Aerosol-induced cloud retrieval error

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- Neglect of above-cloud smoke aerosols leads to an underestimate of cloud optical depth (COD) by ~15%, which is close to the number (10-20%) given by Alfaro-Contreras et al. (2014)
- COD retrieval error is proportional to optical depth of cloud and above-cloud aerosols

Correlated multi-pixel inversion (CMPI)

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- Aerosol remote sensing is subjected to ill-posedness
 - Solution is non-unique due to insufficient information in observations
 - High dimensionality of parameter space causes inversion instability and large computational burden
- We utilize aerosol spatial and temporal correlations and developed (*Xu et al., 2019*)
 - a correlated multi-pixel inversion (CMPI) approach that optimizes over a reduced parameter space
 - a fast multi-pixel radiative transfer modeling approach

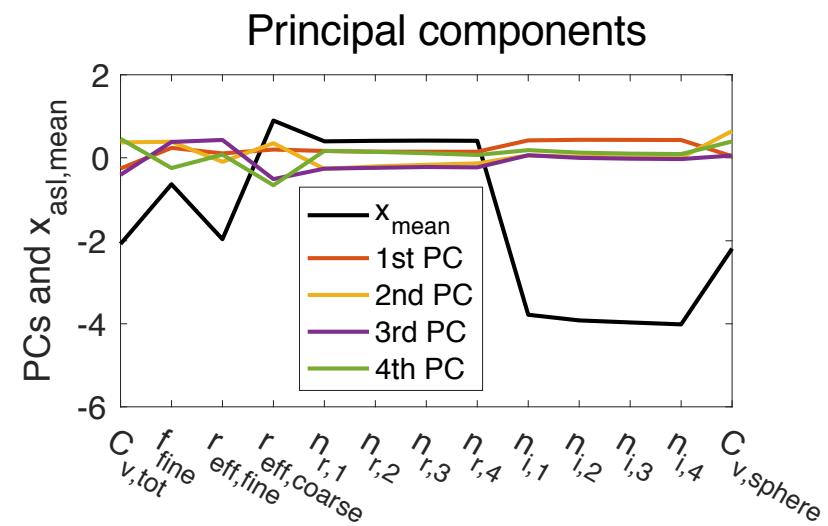
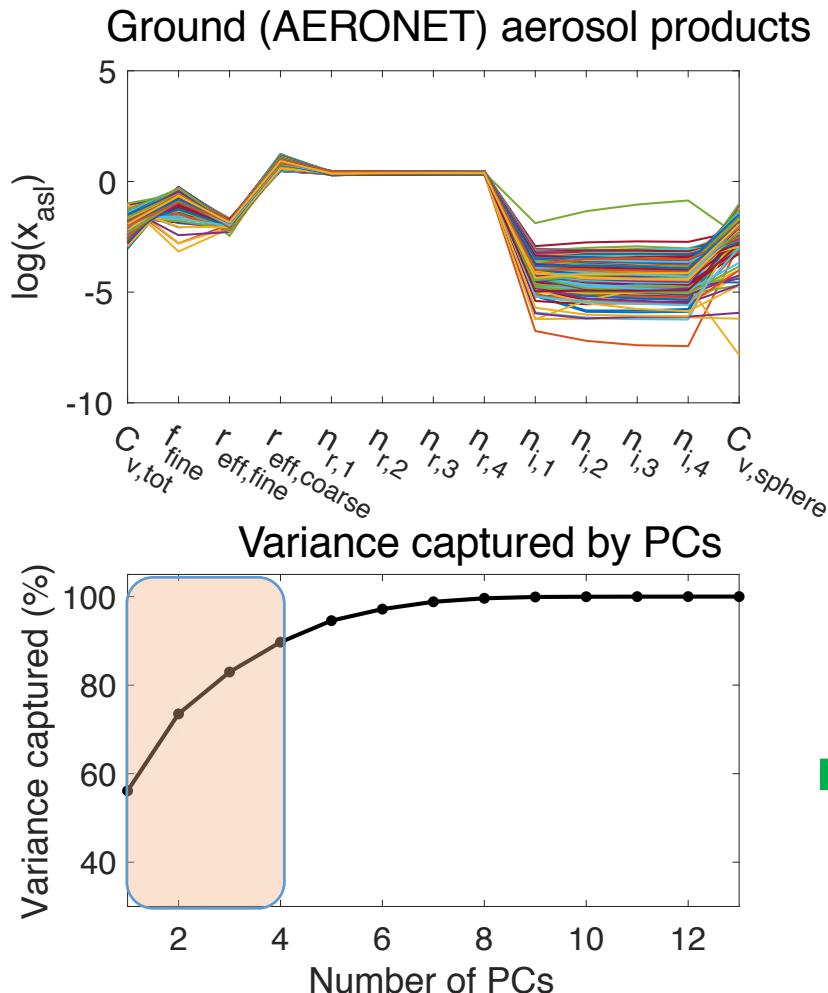


Three types of lower boundaries considered in CMPI aerosol retrievals.

Aerosol correlation utilized in CMPI retrieval

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2000 km domain around AERONET **Namibe site, Angola**



Aerosol parameters are highly correlated in nature but a few principal components (PCs) capture ~85-90% temporal and spatial variance of aerosol properties.

CMPI algorithm features

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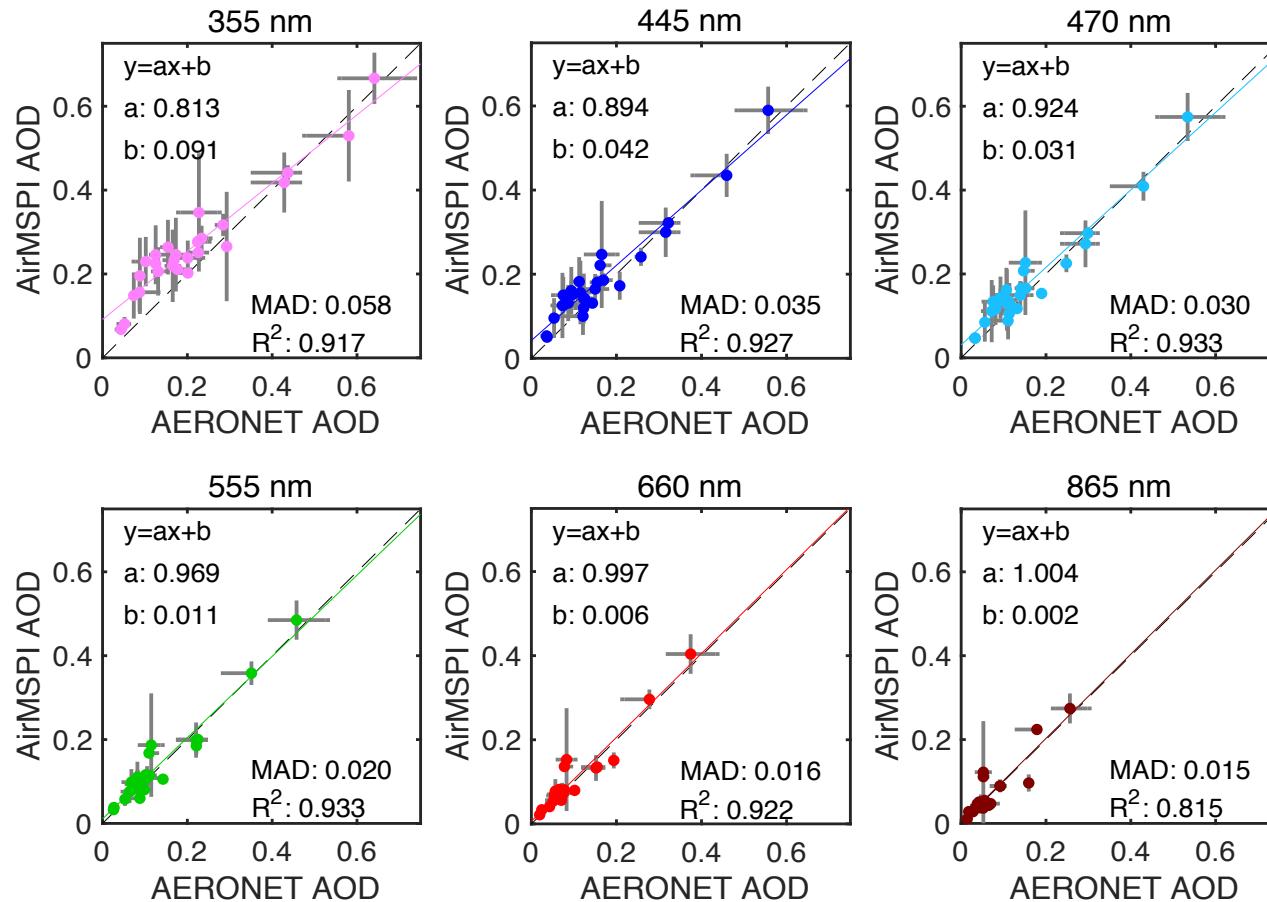
- Reduces aerosol parameter space by retrieving principal components (PCs)
Total parameter space reduces by 2 magnitudes for an 1000x1000 pixel image
- Allows climatology/transport model to inform retrieval
Compensates insufficient information in a single type of remote sensing data
- Imposes multiple types of constraints on stabilize PC retrievals
Example: aerosols have smooth spatial variations and surface has smooth temporal variations



CMPI validation against AERONET AOD

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Aerosol Optical Depth (AOD)



Ground (AERONET) AOD
error bar: ±1 hr window
statistics plus retrieval
uncertainty estimate
(Dubovik and King, 2000)

AirMSPI AOD error bar:
statistics over the
image plus retrieval
uncertainties (Xu et al.,
2019, submitted)

28 AirMSPI scenarios acquired during NASA multiple field campaigns,
collocated with AERONET sites for retrieval validation

Fast multi-pixel radiative transfer simulation

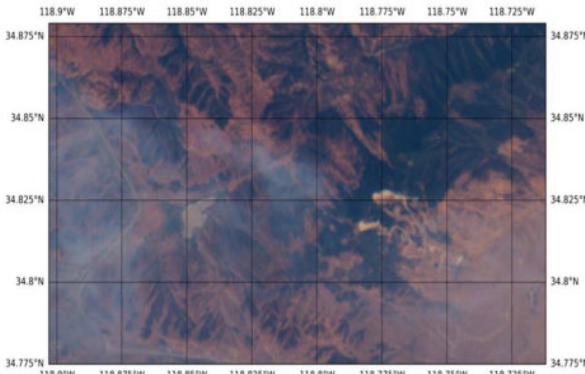
20

$$\mathbf{Y}(\mathbf{x}_p) \approx \mathbf{Y}(\bar{\mathbf{x}}) + \sum_{k=1}^{N_{PC}} \left[\frac{\mathbf{Y}(\bar{\mathbf{x}} + \delta \times \mathbf{v}_k) - \mathbf{Y}(\bar{\mathbf{x}} - \delta \times \mathbf{v}_k)}{2\delta} w_{p,k} + \frac{\mathbf{Y}(\bar{\mathbf{x}} + \delta \times \mathbf{v}_k) - 2\mathbf{Y}(\bar{\mathbf{x}}) + \mathbf{Y}(\bar{\mathbf{x}} - \delta \times \mathbf{v}_k)}{2\delta^2} w_{p,k}^2 \right]$$

↑
Y: pixel AOD, refl.
or trans. matrix **̄x**: field
mean

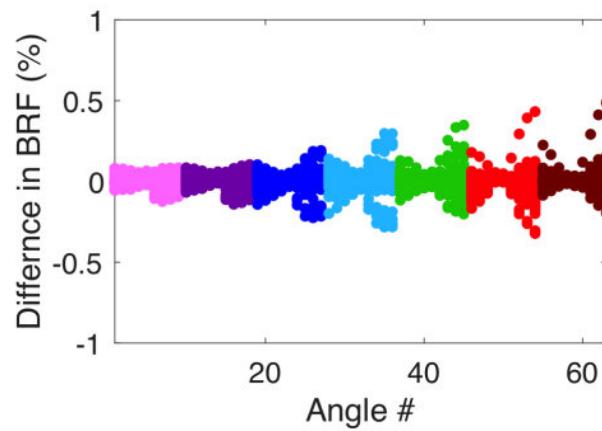
v: PC vectors
(image-effective) **w**: PC weights
(pixel resolved)

δ: perturbation

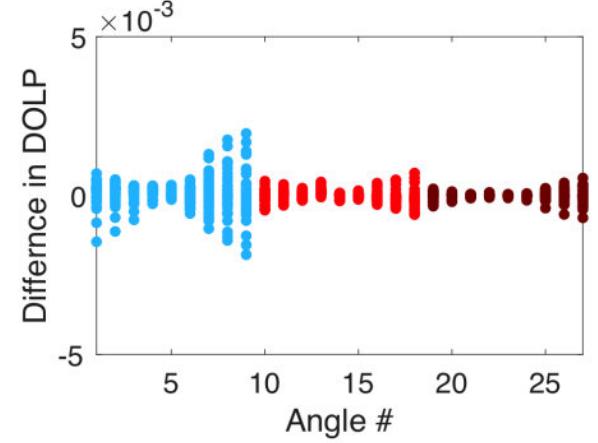


Xu et al., 2019

PCA-RT error (%) in multi-pixel
TOA angular **BRF** in 7 bands



PCA-RT error in multi-pixel TOA
angular **DOLP** in 3 bands



Summary

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- ❖ In response to the last Decadal Survey, AirMSPI instrument and algorithms were developed, validated, and utilized in multiple NASA field campaigns for polarimetric aerosol and cloud remote sensing.
- ❖ We observed correlations in cloud-top droplet size and cloud optical depth, which enables a pixel-scale droplet size distribution estimate.
- ❖ A correlated multi-pixel inversion approach was developed for improving aerosol remote sensing accuracy by a) reducing the retrieval parameter space; b) allowing model & ground data to inform retrievals.
- ❖ A correlated radiative transfer modeling approach was developed for polarimetric aerosol and cloud remote sensing.

Thank you



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